Restrictor Modeling in WinStorm/HouStorm
and Other Steady State Applications

By James F. Thompson, P.E.
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The modeling of restrictors and other such orifices in WinStorm and HouStorm and other steady state applications can be accommodated by the inclusion of an equivalent restrictor pipe that emulates the behavior of the orifice. To accomplish this, build the Win/HouStorm model as you normally would with all drainage areas, nodes, and links; however, include a 10-ft. section of conduit at the orifice location in the model that matches the incoming conduit size and Manning's *n*. This 10-ft. conduit will later be resized to match the behavior of the orifice and can be set with zero slope as to not affect the upstream and downstream conduit invert elevations; however, you will get an error dialog box of negative slope which can be annoying if you have multiple restrictor locations in the model. To avoid this, simply set the downstream invert elevation 0.01-ft. below the upstream invert elevation of the conduit emulating the restrictor.

Next, run this model using the desired storm frequency in an analysis mode and note all the flows within the conduits at the orifice locations. This is the Q that is used in the calculation of the equivalent pipe size. Now the head loss is calculated using either Equation 1 or 2. The actual loss through an orifice in our conventional storm sewer applications has not been widely studied. There are applications from the petrochemical industry that do apply; yet, the overall examination of the behavior of orifices (i.e. restrictors) in large storm sewer projects has not been very well documented. Basically, the issue is the behavior of energy dissipation through the orifice as opposed to pressure differential in submerged conditions as is typically seen in many areas of Texas, especially along the Gulf Coast. Pressure recovery is a function of many variables, one of which is downstream velocity recovery. The actual behavior of the orifice, in terms of considering pressure recovery downstream, is most aptly calculated using a function of the ratio of the orifice diameter to the incoming pipe diameter. If you are using box culverts or square orifices, then an equivalent area must be calculated and then use the resulting diameter. In straightforward terms, use Equation 1 if your initial Win/HouStorm model run shows the pressure head or HGL of the conduits on both sides of the orifice is higher than the pipe soffit (i.e. the pipe is surcharged), and use Equation 2 if the conduit downstream of the orifice is flowing partially full. In either case, use the applicable equation to solve for the head loss through the orifice. This is only a very cursory overview of the hydraulics of orifices used as restrictors and energy dissipaters and much more information can be obtained from suitable sources.[1,2]

Using Equation 3, which is a form of Manning's Equation, calculate the area and resultant diameter of the equivalent, 10-ft. long, restrictor pipe. Notice that Equation 3 can be made to be an explicit calculation for round pipe by solving the equation in terms of the diameter of the pipe in lieu of the area; however, box culverts require an iterative calculation using the hydraulic radius in the function as shown. (Note: a further variation could be to set the equivalent pipe opening to the diameter, or equivalent diameter, of the orifice and solving for *n*). After solving for the area and resultant diameter

[1] Brater and King, 1976. *Handbook of Hydraulics, Sixth Edition,* McGraw-Hill, Inc.
[2] International Organization of Standards (ISO 5167-1). 1991. *Measurement of fluid flow by means of pressure differential devices, Part 1: Orifice plates, nozzles, and venture tubes…*

of the equivalent 10-ft. long pipe, adjust the initial Win/HouStorm model to reflect the restrictor diameter(s) calculated at all locations. After re-running the model, a check can be made of the output to insure that the head loss generated through the equivalent pipe approximates the head loss calculated using either Equation 1 or 2 as applied. A sample calculation of this application is attached. Notice that the calculated head loss in Win/HouStorm will not necessarily exactly match the calculated head loss using the below equations. This is due to two reasons: 1) Win/HouStorm uses rounding to two significant digits in terms of pipe diameter and even the slightest variation in diameter can make a noticeable difference in head loss; and 2) Win/HouStorm calculates the HGL and resultant friction slope in an iterative process by adding 0.01-ft. to the downstream HGL and calculating the upstream length of conduit required to match that given HGL elevation – a process that typically will not exactly converge on the given upstream junction location. Win/HouStorm could be run a few times afterwards to slightly vary the orifice equivalent pipe diameter slightly to converge upon the exact desired head loss as calculated using Equations 1 or 2. Some intuitive engineering judgment should be used in deciding the relative accuracy needed in the solution.

$$h_\ell = \frac{\sqrt{1-\beta^4} - C\beta^2}{\sqrt{1-\beta^4} + C\beta^2} \times \frac{Q^2(1-\beta^4)}{2gC^2A^2} \qquad \text{(Eq. 1)}$$

Where: h_ℓ = head loss, ft.
β = ratio of orifice diameter to incoming pipe diameter
C = orifice coefficient = 0.67
A = area of orifice, ft.^{2}
Q = flow, cfs
g = gravitational constant = 32.2 ft./sec^2

$$h_\ell = \frac{Q^2}{2gC^2A^2} \qquad \text{(Eq. 2)}$$

Where: terms are the same as in Eq.1

$$AR^{2/3} = \frac{Qn}{1.49 \times \sqrt{\frac{h_\ell}{L}}} \qquad \text{(Eq. 3)}$$

Where: R = hydraulic radius, ft.
n = Manning's coefficient
L = conduit length, ft.
Other terms as previously applied

Given: 48" Ø pipe w/ a 36" Ø orifice restrictor
& $Q = 50$ cfs

Find: The equivalent round pipe size using $n = 0.013$ for input into HouStorm; pipe length, L, $= 10'$

Seeing that the pipes on both sides of the orifice are under pressure (i.e. full), use:

$$h_\ell = \frac{\sqrt{1-\beta^4} - C\beta^2}{\sqrt{1-\beta^4} + C\beta^2} \times \frac{Q^2(1-\beta^4)}{2gC^2A^2}$$

$A = \pi d^2/4 = 7.07'$

$\beta = 3/4 = 0.75$

$$\therefore h_\ell = \frac{\sqrt{1-0.75^4} - (0.67)0.75^2}{\sqrt{1-0.75^4} + (0.67)0.75^2} \times \frac{50^2(1-0.75^4)}{64.4(0.67)^2(7.07)^2}$$

$= 0.44$ ft.

Solve for A:

$$AR^{2/3} = \frac{Qn}{1.49\sqrt{h_\ell/L}} = \frac{50\,(0.013)}{1.49\sqrt{0.44/10}} = 2.0797$$

$A = 3.2608$ ft^2 through iteration

& $D = 2.0376$ ft

Note: HouStorm can only take 2 significant digits, $\therefore$ use $D = 2.04$ ft.

After iterative runs in HouStorm, this dia. value could be revised to 2.01 ft. to yield an exact match of $h_\ell = 0.44$ ft.

HouStorm (City Of Houston STORM DRAIN DESIGN) Version 2.0, 11/16/03
Run @ 6/23/2004 10:08:31 AM

PROJECT NAME : Restrictor Test
JOB NUMBER :
PROJECT DESCRIPTION : Testing the Modeling of a Restrictor
PROJECT File: C:\Winstorm Seminar\Restrictor Test.stm

ANALYSYS FREQUENCY : 2 Years
MEASUREMENT UNITS: ENGLISH

OUTPUT FOR ANALYSYS FREQUENCY of: 2 Years

Runoff Computation for Design Frequency.

ID	C Value	Area (acre)	Tc (min)	Tc Used (min)	Intensity (in/hr)	Supply Q (cfs)	Total Q (cfs)
A-1	0.0	0.00	10.00	0.00	0.00	50.000	50.000

Cumulative Junction Discharge Computations

Node I.D.	Node Type	Weighted C-Value	Cumulat. Dr.Area (acres)	Cumulat. Tc (min)	Intens. (in/hr)	User Supply Q cfs)	Additional Q in Node (cfs)	Total Disch. (cfs)
A-1	CrcMh	0.000	0.00	0.00	0.00	50.000	0.00	50.000
A-2	CrcMh	0.000	0.00	10.00	4.96	50.000	0.00	50.000
A-3	CrcMh	0.000	0.00	10.00	4.96	50.000	0.00	50.000
OUT	Outlt	0.000	0.00	10.00	4.96	50.000	0.00	50.000

Conveyance Configuration Data

equivalent pipe dia.

Run#	Node I.D. US	Node I.D. DS	Flowline Elev. US (ft)	Flowline Elev. DS (ft)	Shape	#	Span (ft)	Rise (ft)	Length (ft)	Slope (%)	n_value
1	A-1	A-2	30.00	29.88	Circ	1	0.00	4.00	100.00	0.12	0.013
2	A-2	A-3	29.88	29.87	Circ	1	0.00	2.04	10.00	0.10	0.013
3	A-3	OUT	29.87	29.76	Circ	1	0.00	4.00	100.00	0.11	0.013

Conveyance Hydraulic Computations. Tailwater = 34.760 (ft)

Run#	Hydraulic Gradeline US Elev (ft)	Hydraulic Gradeline DS Elev (ft)	Fr.Slope (%)	Depth Unif. (ft)	Depth Actual (ft)	Velocity Unif. (f/s)	Velocity Actual (f/s)	Q (cfs)	Cap (cfs)	Junc Loss (ft)
1	35.38	35.27	0.111	3.28	4.00	4.53	3.98	50.00	51.99	0.000
2	35.27	34.87	4.026	2.04	2.04	15.30	15.30	50.00	7.88	0.000
3	34.87	34.76	0.111	3.50	4.00	4.29	3.98	50.00	49.78	0.000

Total h_l = 0.4026 (L × frict. slope)

Note: If I input the dia. of the equivalent as 2.01', then I exactly match the 0.44' of h_l.